

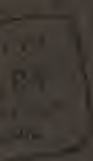
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THE IMPROVEMENT OF SPEED AND ACCURACY IN TYPEWRITING

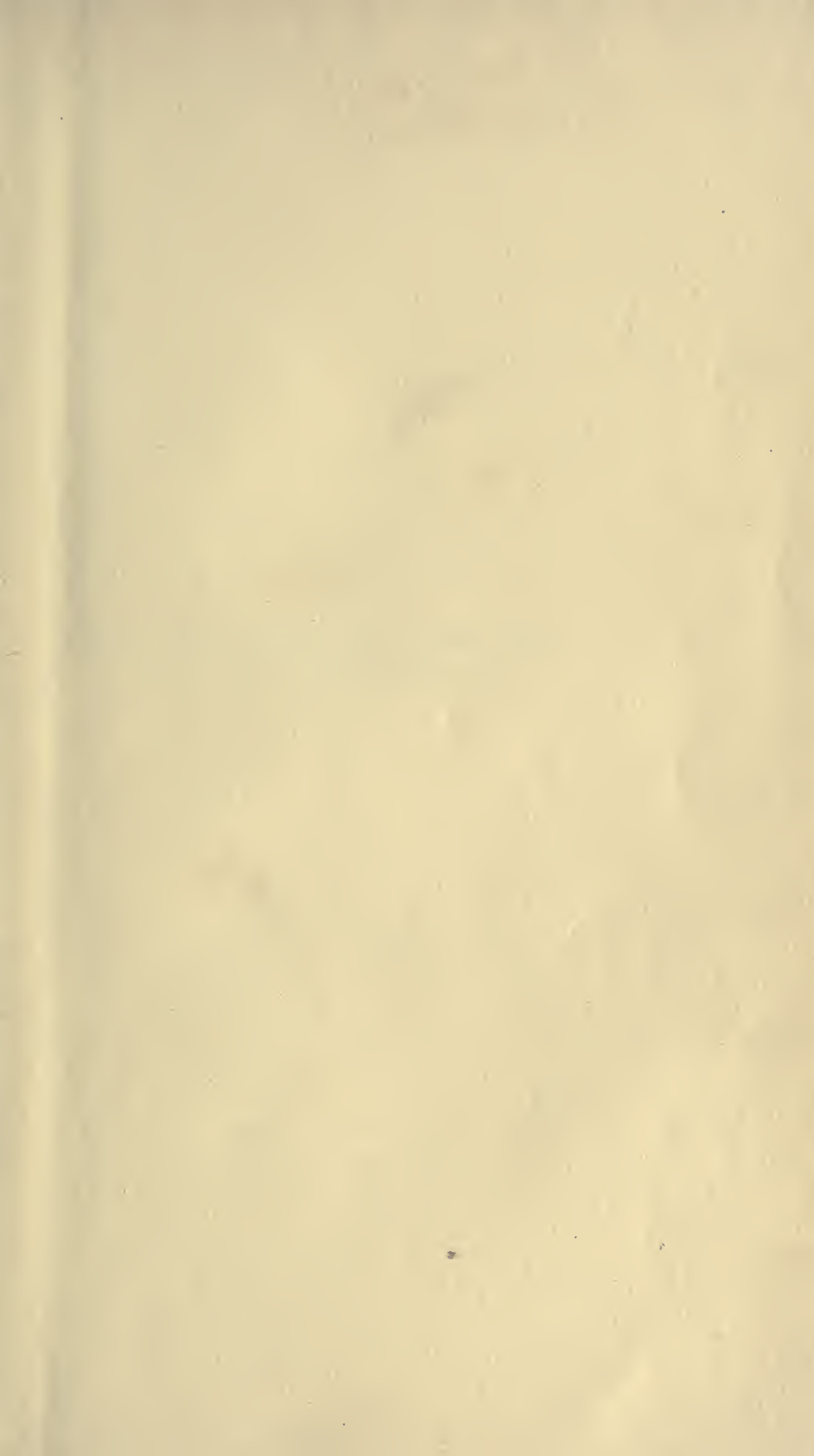
A dissertation submitted to the Board of
University Studies of the Johns Hopkins
University in conformity with the require-
ments for the degree of Doctor of
Philosophy
1922

BY
ROY EDWARD HOKE



BALTIMORE
THE JOHNS HOPKINS PRESS
1922

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TO MR. J. B. SOWERS

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INTRODUCTION

Some time ago the writer began work on the problem of constructing standard tests in typewriting, such as have been and are being formulated for the various subjects of the elementary and secondary school curricula. The first preliminary investigations, however, revealed the fact that there were other typewriting problems which might logically claim priority. First, since typewriting is a matter entirely of the use of the letters of the alphabet and the various marks, it seemed necessary to investigate the frequency of the occurrence of these letters and marks in the English language. Secondly, since accuracy is one of the primary requisites of good typewriting, it appeared to be important to investigate the number and distribution of errors made in actual typewriting, and to learn, if possible, their causes. Third, the modern "touch" method of typewriting presumably makes equal demands upon all the fingers and upon the two hands. In fact, the typewriter keyboard is so arranged as to assign fifteen letters to the left hand, and only eleven to the right. The problem arises: what are the relative abilities of the eight fingers and the two hands. Fourth, the determination of the loads or burdens of work which the present typewriter keyboard places upon the fingers and hands. Fifth, an attempt to enumerate the considerations which must be taken into account in the arrangement of a keyboard according to scientific principles; a suggested keyboard, and the criticism of the same from the considerations set forth.

The field of this investigation is one that has not been cultivated. With the exception of the work by Book on "The Psychology of Skill," little or no experimentation has been done in typewriting. Even in Book's study, the object was not so much the improvement of speed, accuracy or methods of teaching typewriting, as it was the more general aim of ascertaining, by the use of the typewriter as a mere

bit of apparatus, the psychology of skill. Any other mechanism, an adding machine or piano for instance, would have been equally capable of use in a study of skill, though perhaps not equally convenient for experimental purposes.

I. THE FREQUENCY OF THE OCCURRENCE OF LETTERS AND MARKS IN THE ENGLISH LANGUAGE

The first objective of the problem under consideration is to determine the frequency with which the various letters of the alphabet and the more common marks are used in the English language. For this purpose valuable material was readily at hand as to the letters in the form of the Ayres Spelling Scale. This scale itself informs us that the 1,000 words in the list are "the product of combining different studies with the object of identifying the 1,000 commonest words in English writing." The scale was formed by combining four different vocabulary studies as follows: (1) A study by Ayres himself involving a total of 23,629 words found in personal and business letters. (2) The study of Eldridge comprising 43,989 words found on two pages each of four different newspapers. (3) The study of Rev. Knowles of London, of the vocabulary of the English Bible and various authors, to a total of 100,000 words. (4) The study of Cook and O'Shea of the vocabulary used by thirteen persons in family and social correspondence, including a total of 5,200 different words. Most of these words occurred a number of times. It will be seen, therefore, that the 1,000 words in the Ayres Scale are those that were found most frequently in approximately 368,000 words of personal letters, business letters, newspapers, the Bible, and various English authors.

Accepting the 1,000 words of this list as the most common in the English language, it would appear that by counting the frequency with which the various letters of the alphabet appear in these words, we should secure a very close approximation to their frequency in the English language in general, and in the work done on typewriters in particular.

12 THE FREQUENCY OF LETTERS AND MARKS IN ENGLISH

Table I shows in the first column the gross number of occurrences of each letter of the alphabet in the 1,000 commonest words. A total of 5,433 letters were found. The average length of the words, therefore, is 5.433 letters. By multiplying the number of occurrences of each letter by

TABLE I
FREQUENCY OF USE OF LETTERS IN THE WORDS OF THE AYRES
SPELLING SCALE

	Times Used	Raised to 1000	Percentage	Based on "Q"
E	734	1000	13.51	245
T	440	609	8.09	147
R	434	591	7.98	145
A	419	571	7.71	139
O	385	524	7.08	128
N	373	508	6.88	124
I	366	598	6.73	122
S	308	420	5.66	103
L	254	350	4.67	85
C	219	298	4.03	73
D	193	263	3.51	64
U	171	233	3.14	57
H	170	232	3.12	56
P	161	219	2.96	54
M	154	210	2.81	51
G	114	155	2.09	38
F	113	154	2.07	37
Y	107	146	1.96	36
B	97	132	1.78	32
W	90	123	1.65	30
V	60	82	1.09	20
K	36	49	.66	12
J	14	19	.25	5
X	13	18	.23	4
Z	5	7	.09	2
Q	3	4	.05	1
Total	5433	7415	100.%	1790

1.362 we secure the second column of the table, in which "E" is raised to 1,000. This was done so as to put each letter on a comparable basis. The third column shows the percentage of English writing that is made up by each letter of the alphabet. The fourth column gives the frequency of the letters with reference to "Q" as one. From this column it will be noted that for each use of the letter "Q," the letter "E" occurs 245 times.

Although the evidence thus secured for the frequencies of letters seemed almost conclusive, it was nevertheless thought desirable to support it by corroborative evidence from original studies. With this purpose in view, three studies were made on the frequencies of letters and punctua-

TABLE II

FREQUENCY OF USE OF LETTERS AND PUNCTUATION MARKS IN THE SIXTEENTH CHAPTER OF MARK'S GOSPEL

	Times Used	Raised to 1000
E	271	1000
T	164	605
A	155	572
H	153	565
N	106	391
S	92	340
D	92	340
O	88	325
I	87	321
R	67	247
L	63	232
Y	52	192
M	41	151
U	37	137
W	37	137
P	25	92
C	23	85
F	23	85
B	20	74
G	13	48
V	12	44
K	6	22
Z	3	11
J	2	7
Q	1	4
X	0	0
.	19	70
,	34	125
:	6	22
;	11	41

tion marks in (1) the Gospel of St. Mark, (2) representative business letters, and (3) current newspaper editorials.

Table II shows the frequencies of use of letters and punctuation marks in the sixteenth chapter of Mark's Gospel. The first column shows the actual occurrences of letters, while the second column shows the same data with "E"

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raised to 1,000 for purposes of comparison. This was done by multiplying the first column through by 3.69.

Table III shows the frequencies of use of letters and punctuation marks in actual business letters. The first col-

TABLE III
FREQUENCY OF USE OF LETTERS AND PUNCTUATION MARKS IN BUSINESS LETTERS

	Times Used	Raised to 1000
E	354	1000
A	252	720
O	249	711
T	240	686
N	195	557
S	162	463
I	156	446
L	147	420
H	144	411
R	135	386
D	96	274
C	93	265
U	90	260
M	75	214
Y	72	205
B	51	146
W	48	137
P	33	94
G	30	86
V	24	69
F	18	51
K	12	34
X	9	25
J	6	17
Q	3	8
Z	3	8
.	44	124
,	49	140
:	4	12
:	0	0

umn, again, shows the original data secured by count, while the second column shows the same data with "E" raised to 1,000 by multiplying through by 2.82.

Table IV shows the frequencies of use of letters and punctuation marks in a newspaper editorial both in the original form as counted and also as these data appear when raised to the basis of 1,000 for "E" by multiplying by 3.97.

A comparison of the data of these three original studies with Table I, which gives the frequency of letters only in the Ayres Spelling Scale, with the letter "E" raised to 1,000 for purposes of comparison, will reveal much similarity both

TABLE IV

FREQUENCY OF USE OF LETTERS AND PUNCTUATION MARKS IN A
NEWSPAPER EDITORIAL

	Times Used	Raised to 1000
E	252	1000
A	219	876
T	210	841
S	180	723
O	171	685
I	168	673
R	117	468
N	105	420
H	102	409
L	99	396
B	72	289
C	69	276
U	66	263
P	57	228
M	54	216
D	42	169
Y	39	157
W	33	132
F	30	120
G	27	109
V	18	71
K	15	60
J	12	49
X	9	37
Q	6	24
Z	3	11
.	16	64
,	20	81
:	0	0
!	2	7

in the order or rank of the letters and in the four tables. It may justly be said that the differences in the four tables are less noticeable than the similarities. This fact may be given more definite and exact expression statistically. The frequencies of letters in the Ayres Scale correlate with the frequencies found by averaging the three original studies (Tables II, III and IV) almost perfectly. The coefficient

of correlation is .946 and the probable error is .012. The product-moment formula was used in securing this correlation.

It is of course possible that in any one study of the frequency of letters the chance presence or absence of a few words containing the less common letters, such as K, J, Q, X or Z, may appreciably influence the result. This difficulty

TABLE V
STUDIES ON THE FREQUENCY OF USE OF LETTERS AND PUNCTUATION MARKS

	Ayres	Mark	Business Letters	Editorial	Average
E	1000	1000	1000	1000	1000
T	609	605	686	841	685
A	571	572	720	876	684
O	524	325	711	685	561
S	420	340	463	723	486
I	498	321	446	673	484
N	508	391	557	420	469
R	591	247	386	468	423
H	232	565	411	409	402
L	350	232	420	396	349
D	263	340	274	169	261
C	298	85	265	276	231
U	233	137	260	263	223
M	210	151	214	216	198
Y	146	192	205	157	175
B	132	74	146	289	160
P	219	92	94	228	158
W	123	137	137	132	132
F	154	85	51	120	102
G	153	48	86	109	99
V	82	44	69	71	66
K	49	22	34	60	41
J	19	7	17	49	23
X	18	0	25	37	20
Q	4	4	8	24	10
Z	7	11	8	11	9
·		70	124	64	86
,		125	140	81	115
:		22	12	0	11
;		41	0	7	16

may be obviated by combining the four studies, to which procedure no objection may be raised in view of the very high correlation which obtains, as set forth above.

Table V shows the frequencies of letters and marks in the four studies made, all raised to the basis of 1,000 for "E,"

while in the fifth column of the table we have the average of the first four. This column is based on the counting of 12,130 letters of the alphabet in connection with the four studies. The findings set forth in this fifth column are accepted in this study as a basis for evaluating the various letters and marks and their importance or frequency in typewriting.

TABLE VI

FREQUENCY OF USE OF LETTERS AND PUNCTUATION MARKS IN
PRINTER'S FONTS AS COMPARED WITH AVERAGES
GIVEN IN TABLE V

	Printer's Font		Av. this Study
E	12,000	1000	1000
T	9,000	750	685
A	8,500	708	684
O	8,000	667	561
S	8,000	667	486
I	8,000	667	484
N	8,000	667	469
R	6,200	517	423
H	6,400	533	402
L	4,000	334	349
D	4,400	367	261
C	3,000	250	231
U	3,400	283	223
M	3,000	250	198
Y	2,000	167	175
B	1,600	133	160
P	1,700	142	158
W	2,000	167	132
F	2,500	208	102
G	1,700	142	99
V	1,200	100	66
K	800	67	41
J	400	33	23
X	400	33	20
Q	500	42	10
Z	200	17	9
	In font of 100 "e"		
.	40	400	86
,	40	400	115
:	5	50	11
;	5	50	16



Fig.1. Graphic Representation of the Frequency of the Use of Letters.

Figure 1 shows graphically the frequency of the various letters. The fact is that the first six letters (E, T, A, O, S, I) are used more frequently than the remaining twenty letters. The most startling observation is the fact that "E" is used more frequently than twelve other letters combined (Y, B, P, W, F, G, V, K, J, X, Q, Z). In view of these facts the conclusion is very evident, viz., that the frequencies of the letters must be taken into consideration and form the basis for any scientific arrangement of the typewriter keyboard.

In further corroboration of the findings of this study as to the frequencies of letters and marks, the custom of the printing trade may be adduced. Table VI represents in the first column the number of type of each letter included in a large printer's font, the same for comparative purposes being reduced to the basis of 1,000 for "E" by dividing through by 12, and the results shown in the second column. Our accepted findings are given in the third column. Even a casual comparison of these data reveals so close an agreement between them that a correlation by statistical methods would be superfluous. It needs, however, to be borne in mind that the printer's font supplies a somewhat larger number of the less common letters and marks than would be usually found necessary. Furthermore, the fact that in the printer's font four letters (O, S, I, N) are given the same rank, with 8,000 type each, indicates that we have here only a rough approximation of usage, and that the evidence from the make-up of the font is valuable for our purpose for corroboration only and not for the definite evaluation of letters.

II. ERRORS IN TYPEWRITING AND THEIR CAUSES

For the purposes of this part of our investigation about 500 full size pages of practice typewriting work were secured, from approximately 100 different individuals, and the errors found therein counted and tabulated up to the point where "E" was charged with 1,000 errors. This point was reached when all but three pages of the material had been checked. The errors for the several letters are given in Table VII,

TABLE VII
ERRORS MADE IN ACTUAL TYPEWRITING AS COMPARED WITH FREQUENCY OF OCCURRENCE OF LETTERS

	Frequency	Errors	Percentage
E	1000	1000	100.
T	685	636	92.8
A	684	596	87.1
O	561	462	82.4
S	486	395	81.3
I	484	378	78.1
N	469	372	79.3
R	423	440	104.
H	402	223	55.5
L	349	339	97.1
D	261	418	160.1
C	231	283	122.5
U	223	224	100.
M	198	321	162.1
Y	175	246	140.6
B	160	97	60.6
P	158	73	46.2
W	132	84	63.6
F	102	209	204.9
G	99	325	328.2
V	66	158	239.4
K	41	96	234.1
J	23	26	113.
X	20	140	700.
Q	10	32	320.
Z	9	20	222.2
Median			108.3

and for convenience of comparison our adopted scale of frequencies of use is given therewith. The percentage rela-

tionship between these two series of data is given in the third column of Table VII, from which it will be seen that twelve letters are as good or better than "E" from the standpoint of accuracy, while thirteen rank below "E." The median is 108.3.

The relationship between accuracy and frequency of use may be definitely calculated by the use of the product-moment formula. The coefficient of correlation is found to be .924

TABLE VIII
COMPARISON OF FREQUENCY OF USE OF LETTERS WITH ACCURACY

	Above Md. in frequency of use +, below —.	Above Md. in number of errors +, below —.	Above Md. in percentage of accuracy +, below —.
E	+	+	+
T	+	+	+
A	+	+	+
O	+	+	+
S	+	+	+
I	+	+	+
N	+	+	+
R	+	+	+
H	+	—*	+
L	+	+	+
D	+	+	—
C	+	+	—*
U	+	—*	+
M	—	+	—
Y	—	—	—
B	—	—	+
P	—	—	+
W	—	—	+
F	—	—	—
G	—	+	—
V	—	—	—
K	—	—	—
J	—	—	—
X	—	—	—
Q	—	—	—
Z	—	—	—

with a P. E. of .021. This shows a very close relationship between use and accuracy and bears out the adage, "Practice makes perfect."

This relationship is set forth in a more graphical way in Table VIII. In the upper half of this table we have the

*The exceptions noted are very near the medians.

thirteen most used letters, in the lower half the thirteen least frequent letters. In the first column the frequency of use of letters is indicated by a plus sign for those letters above the median in use, and a minus sign for those below the median. In the second column a plus sign indicates those letters above the median in number of errors, and a minus sign those below the median in number of errors. There are only two of the thirteen most common letters which are below the median in number of errors, and then by a very narrow margin. Also only two of the thirteen least used letters are above the median in number of errors, nor then by very large margins. In the third column the plus sign indicates those letters which are above the median in percentage of accuracy, while the minus sign indicates those letters which are below the median in accuracy. With five exceptions out of the 26 letters, frequency of use and accuracy go together, or infrequency of use with inaccuracy. One of the five exceptions is by a negligible difference.

We had expected to find that some keys, or rows of keys, on the typewriter would be more accurate than others. The findings contradict this expectation, and indicate that the position of keys on the present keyboard exercises very little if any measurable effect upon accuracy. It has not been found possible to say with any degree of assurance that any one position on the keyboard is better than any other from the standpoint of accuracy.

A further study has been made to ascertain whether the errors made in typing any letter are more likely to occur in combination with certain letters than with others. To answer this question errors were tabulated until 100 had been noted for "E," and in each case the letter after which the error occurred was noted. The results of this study are set forth in Table IX. This table should be read as follows:

TABLE IX

ERRORS AND THE LETTERS AFTER WHICH THEY OCCURRED

E	M20, L14, R12, N12, S6, T6, V5, H5, Z5, K3, F3, B3, O2, G2.
T	O10, A9, I8, S8, N4, C4, E3, F3, B3, U3, O3.
R	E16, O10, A10, M4, H3, P3.
A	H10, T10, O4, W4, E3, D3, R2, C2, F2, M2, S1, V1.
S	E10, A12, I4, R4, U5, T2, O2, N2, B2.
N	N9, A8, O8, R3, U2, I2.
O	L8, R6, Y5, D4, T4, G2, H2, O2, E2, W2.
I	H6, L5, P4, W2, M2, V2, R2, K2, A2, N2.
D	E12, O8, N4, L2, V2, R1.
L	U6, P6, E4, F2, O2, A2, I2, G2, R1, B1.
G	N11, E4, A4, T2, R1, O1.
H	W6, P5, C4, T4, G2, A1.
M	O6, I4, U2, E2, L2, R2, S1.
U	O6, R4, B3, Y2, D2, G1, H1.
Y	A6, N4, B3, T2, F2, R2, N2, H2, C1.
C	E8, A4, I2, N2, S2, U1.
V	A5, I4, O4, N3, E2, R1.
W	A8, S7.
F	A3, E2, O2, N1.
B	R2, I2, M2, O1, U1.
K	O2, R2, I2, N1, A1.
P	H3, I2, U1, E1.
X	A3, O2, I2, E1.
Q	E2.
J	A2.
Z	D2, A1.

Tabulating from the above the errors made after each of the letters we get the following: After E 81 errors, A 81, O 75, N 46, R 45, I 34, H 32, L 31, M 30, T 30, S 25, U 22, P 18, B 15, W 14, F 12, C 11, D 11, V 10, G 7, Y 7, K 5, Z 5, J 0, Q 0, X 0. Inspection shows that this correlates very highly with the frequency of use of letters, which would indicate merely that most errors happen after the letters most frequently used because most trials occur, and therefore most chance for error after the frequently used letters.

of the 100 errors made in writing "E," 20 occurred after M, 14 after L, 12 after R, 12 after N, 6 after S, 6 after T, 5 after V, 5 after H, 5 after Z, 3 after K, 3 after F, 3 after B, 2 after O, and 2 after G. It does not appear from a study of these data that there is any connection between accuracy and the combination of letters with which any one letter may happen to be written. This serves only to confirm the conclusion that accuracy or inaccuracy is the result of frequent or infrequent practice, due to frequent or infrequent use of the letter.

III. RELATIVE ABILITIES OF THE EIGHT FINGERS AND THE TWO HANDS FOR TYPEWRITING

For the purpose of determining the relative abilities of the eight fingers and the two hands three studies were made. The first of these studies was made upon 50 High School girls; the second on 46 High School boys. In those two studies the following method was used. The subjects were instructed to hold the thumb of the right hand against the center of the typewriter frame, in front of the space bar, and to tap the letter "J" with the first finger of the right hand as rapidly as possible. Thirty seconds were allowed. Then with the thumb of the left hand in the same position, the subject tapped with the first finger of the left hand the letter "F" for thirty seconds. Then in the same way, with the right hand second finger "K," left hand second finger "D," right hand third finger "L," left hand third finger "S," right hand fourth finger "I," left hand fourth finger "A," each for thirty seconds. The number of taps leaving their impressions on typewriter paper in the regular way were counted for each of the eight fingers of each of the 96 subjects.

The purpose of holding the thumb against the metal frame of the typewriter was to eliminate, so far as possible, wrist and arm movements, for it was desired to test only finger abilities. It was found that by holding the thumb in this position the subject was compelled to make the taps by relying upon the fingers alone, as was desired for the purposes of the experiment. The results of these two studies are set forth in Tables X and XI.

TABLE X
TAPPING TEST ON TYPEWRITER—HIGH SCHOOL GIRLS
SHOWING NUMBER OF TAPS MADE BY EACH FINGER IN 30 SECONDS

Number of Subject	LEFT HAND				RIGHT HAND			
	Fingers used				Fingers used			
	4	3	2	1	1	2	3	4
	Letters struck				Letters struck			
	a	s	d	f	j	k	l	;
1	112	117	120	125	131	136	113	153
2	122	134	128	150	117	143	143	143
3	89	108	100	96	96	107	112	108
4	130	129	139	138	129	139	143	129
5	131	124	93	146	112	143	133	117
6	103	135	74	135	122	136	131	106
7	121	141	113	150	138	137	144	113
8	72	63	73	64	60	64	68	69
9	115	128	119	78	151	154	172	140
10	84	92	93	150	98	113	120	94
11	76	90	101	77	88	137	113	100
12	99	128	128	130	119	146	151	135
13	118	122	150	140	106	137	115	100
14	105	130	129	128	137	154	165	152
15	90	106	77	135	123	138	113	102
16	93	95	131	140	140	138	112	101
17	74	74	77	77	76	75	76	76
18	119	140	109	120	151	148	150	159
19	85	126	113	148	155	141	152	91
20	117	120	119	144	154	139	136	134
21	109	116	108	123	113	119	124	121
22	91	117	95	128	103	139	144	121
23	138	131	149	131	139	151	161	153
24	76	117	99	115	101	116	81	80
25	103	110	107	121	89	114	127	98
26	88	102	115	103	108	109	96	90
27	88	103	111	110	107	113	107	114
28	105	143	144	137	147	141	166	156
29	101	117	138	114	122	147	154	152
30	97	117	120	90	116	128	134	119
31	70	92	106	87	107	105	93	75
32	81	101	104	105	101	126	113	103
33	100	119	111	100	109	116	122	99
34	112	122	123	108	141	135	125	146
35	83	122	123	88	117	127	151	128
36	84	94	94	95	84	87	114	110
37	99	130	134	124	129	145	132	154
38	113	132	128	120	135	140	143	149
39	114	104	114	84	81	113	98	106
40	110	125	77	111	126	112	144	118
41	96	104	87	96	99	99	119	112
42	116	130	128	121	150	144	144	145
43	107	131	123	111	112	118	126	127
44	107	108	112	90	140	117	105	134
45	130	128	129	109	121	138	134	147
46	108	118	121	102	119	122	120	127
47	111	127	135	125	121	105	94	92
48	112	109	101	96	100	97	131	134
49	106	109	117	105	120	118	106	100
50	121	110	120	111	125	124	116	110
Averages	103	116	113	115	118	126	126	119
Medians	106	119	117	119	119	130	126	117

TABLE XI

TAPPING TEST ON TYPEWRITER—HIGH SCHOOL BOYS
SHOWING NUMBER OF TAPS MADE BY EACH FINGER IN 30 SECONDS

Number of Subject	LEFT HAND				RIGHT HAND			
	Fingers used				Fingers used			
	4	3	2	1	1	2	3	4
	Letters struck				Letters struck			
	a	s	d	f	j	k	l	;
1	157	169	134	131	156	187	180	132
2	124	142	160	184	205	217	203	152
3	149	154	124	163	150	180	151	179
4	105	108	117	123	141	149	138	93
5	150	152	152	154	154	151	164	160
6	135	150	163	145	177	180	183	173
7	122	138	145	126	166	161	130	159
8	129	158	163	175	165	153	183	152
9	137	130	193	161	158	167	222	167
10	129	121	151	135	163	166	162	134
11	138	143	138	140	139	152	162	154
12	139	140	141	155	159	146	152	136
13	103	126	125	121	178	201	205	183
14	126	172	155	148	181	182	189	167
15	94	79	96	94	88	139	126	119
16	150	146	153	157	179	181	190	149
17	93	115	136	139	179	176	178	137
18	181	186	186	176	181	204	202	181
19	134	138	158	168	173	206	211	195
20	112	143	126	144	141	148	168	121
21	129	129	143	145	158	164	161	169
22	112	128	131	122	167	195	178	153
23	124	117	124	132	186	130	127	147
24	139	131	141	138	157	157	173	169
25	100	122	139	142	153	168	180	121
26	121	134	151	147	150	163	156	134
27	148	139	142	165	150	169	158	148
28	90	101	120	108	125	141	142	119
29	123	110	128	133	120	143	123	136
30	129	131	127	151	154	174	160	171
31	114	126	142	142	165	187	172	153
32	119	129	143	139	140	173	160	150
33	105	118	155	145	172	196	185	171
34	109	99	115	114	132	132	154	137
35	134	139	169	145	130	169	132	140
36	113	104	122	114	151	140	136	123
37	121	122	139	136	133	165	161	140
38	137	135	149	141	135	178	146	134
39	129	138	144	143	132	143	144	144
40	151	154	157	151	151	168	169	150
41	142	149	169	162	142	140	102	101
42	140	151	168	156	165	188	169	140
43	118	116	125	121	145	156	147	157
44	159	156	176	165	199	212	202	175
45	124	139	141	149	154	146	145	136
46	130	129	145	151	158	155	154	150
Averages	128	134	144	143	156	167	164	148
Medians	127	134	145	145	156	166	164	151

An inspection of the medians in these two tables will show that the eight fingers have about the same rank and relative ability for the two sexes. The only noticeable sex difference is in speed of tapping, with respect to which the boys excelled the girls 24.6 per cent.

The third study was made of 42 college girls and 12 teachers of Frederick County, Maryland. In this study a somewhat different method was pursued. The subjects were required to tap for one minute with a pencil with the right hand, then one minute with the left hand. The marks were subsequently counted to get the scores. (A later study showed that when the subjects attempted to count their taps as they went, their speed was impeded. A few reported that this served to increase their scores.) The subjects were further required to tap for thirty seconds upon their desks with each finger. Particular instructions were given as to the position to be assumed: with the wrist resting upon the desk (to prevent wrist movement in tapping) and with three fingers also resting with their tips upon the desk. It was found that this position effectually prevented any wrist or arm movement being used and secured records of the tapping abilities of the fingers alone.

An inspection of the medians for the eight fingers in Table XII shows that they very closely bear out the results of the first and second studies as shown in Tables X and XI. The three studies above involve a total of 190,410 taps, made by 150 different individuals. It is believed that by combining these three studies by the method of averages, we may secure conclusions as to the relative abilities of the fingers and hands which may be relied upon.

TABLE XII
TAPPING TEST—42 COLLEGE GIRLS, 12 TEACHERS

Number of Subject	Taps per min.		Taps in 30 Seconds							
	Right Hand	Left Hand	R1	L1	R2	L2	R3	L3	R4	L4
1	355	306	185	173	159	129	149	117	179	143
2	360	291	159	138	136	138	118	110	116	105
3	446	367	190	187	161	167	149	145	143	159
4	357	318	140	143	108	138	98	98	106	91
5	443	340	189	173	159	154	118	119	124	119
6	386	350	193	154	132	123	80	99	138	119
7	382	314	183	150	113	115	121	103	150	120
8	368	304	200	173	176	129	120	94	110	97
9	324	175	170	160	150	141	135	106	114	106
10	326	254	168	138	150	105	65	72	83	47
11	390	328	170	149	140	129	135	109	76	114
12	387	312	167	142	140	130	75	120	112	118
13	409	299	140	130	119	117	90	70	99	94
14	397	273	153	144	147	127	85	105	109	90
15	417	307	165	140	136	121	102	101	125	121
16	334	299	199	170	160	137	145	144	140	140
17	398	318	187	136	170	127	123	117	147	132
18	359	314	180	130	101	83	99	92	71	79
19	363	286	155	130	126	110	100	100	120	102
20	342	331	146	152	120	132	116	109	137	122
21	342	329	179	165	142	139	95	98	138	140
22	400	378	171	190	156	150	114	130	141	149
23	352	330	151	146	138	125	92	80	115	101
24	326	372	130	120	130	160	100	120	112	120
25	343	271	152	143	126	113	106	90	130	112
26	294	289	126	110	126	111	104	103	118	115
27	383	309	193	160	190	123	97	107	147	109
28	367	282	150	140	149	123	95	103	111	109
29	355	265	136	118	96	94	60	65	74	71
30	322	285	142	123	109	83	100	83	123	93
31	253	291	150	121	149	130	111	80	109	103
32	374	314	101	94	115	100	78	60	110	103
33	407	310	201	165	157	149	145	141	162	147
34	309	226	143	110	103	64	67	78	100	92
35	415	334	201	171	190	167	173	151	179	147
36	354	303	160	136	140	100	87	90	102	106
37	363	326	155	160	132	132	110	108	108	102
38	340	346	160	150	120	120	109	100	118	113
39	434	344	170	170	148	130	106	111	125	110
40	392	288	172	136	132	140	130	123	139	128
41	317	205	157	120	139	122	90	100	122	95
42	281	280	125	98	90	82	65	50	90	75
43	290	292	150	143	146	103	60	62	63	78
44	402	360	135	121	102	101	40	80	81	86
45	332	340	199	215	146	160	82	130	77	102
46	370	300	150	140	55	53	75	60	65	60
47	360	280	199	142	98	82	105	100	110	92
48	400	380	102	114	117	128	40	33	103	114
49	404	342	184	161	167	149	92	104	110	103
50	408	392	155	159	150	122	102	100	119	90
51	374	314	150	118	135	102	108	94	116	89
52	314	374	149	141	164	155	130	140	150	120
53	408	298	123	94	93	76	15	61	70	68
54	472	324	140	115	98	78	59	60	65	62
Averages	363	310	161	143	134	121	101	99	115	106
Medians	365	311	160	145	138	125	104	103	117	107

NOTE.—R1 is used as an abbreviation for "the first finger of the right hand." In the same way the other symbols are to be interpreted.

IV. THE FINGER AND HAND LOADS OF THE PRESENT TYPEWRITER KEYBOARD

Since the foregoing studies make it possible to state in a mathematical form the relative abilities of the two hands and the eight fingers, and the relative values of each letter and mark, it would seem worth while first to raise the question, what is being expected of the fingers and hands by the present typewriter keyboard. We are assuming, of course, that

TABLE XIII

THE TYPEWRITING LOAD OF THE EIGHT FINGERS AND THE RIGHT AND LEFT HANDS

RIGHT HAND				
Fingers	1	2	3	4
y	175	i 484	o 561	p 158
h	402	k 41	l 349	; 16
n	469	, 115	. 86	: 11
u	223			? 11
j	23			Shift 100
m	198			
	1490	640	996	296

Total for the right hand: 3422

LEFT HAND				
Fingers	1	2	3	4
r	423	e 1000	w 152	q 10
f	102	d 261	s 486	a 684
v	66	c 231	x 20	z 9
t	685			Shift 100
g	99			
b	160			
	1535	1492	658	803

Total for the left hand: 4488

the typewriter is to be used by a touch operator. Probably very few persons are any longer disposed to dispute the great advantage of the "touch" method for speed and accuracy. Its advantage from the standpoint of fatigue is still greater.

In accordance with the touch method each of the eight fingers has its own proper keys, three for each finger except the first finger of each hand which has six. Table XIII gives for each finger the letters it strikes and their values, and the sum of these, which is the finger load. These letter values are taken from Table V. Denoting the fingers of the right hand as R1, R2, R3 and R4, and those of the left hand as L1, L2, L3 and L4, we find their loads to be, in the same order: R1, 1,490; R2, 640; R3, 996; R4, 296; L1, 1,535; L2, 1,492; L3, 658; L4, 803. Adding these finger loads for each hand we get the hand loads: for the right hand 3,422, for the left 4,488. In view of the fact that in Tables X, XI and XII we found finger abilities to be not very dissimilar, it is rather startling to find that R1, L1, and L2 are each, on the present typewriter keyboard, given more than five times as much work to do as is given to R4. In view, also, of the generally known fact that the index of right-handedness may be roughly expressed by the ratio of ten to nine, that is, that the ability of the right hand is approximately one-ninth greater than that of the left, it is surprising to find that the present keyboard gives a far heavier load to the weaker member.

The question may be raised: Why are 100 strikes recorded for both the right and left hand Shift Key? This was gotten by actual count, 200 being recorded. However, whether the right hand strikes exactly half of them or not will vary somewhat with the nature of the matter to be written. When a letter on the left side of the present keyboard is capitalized the right shift key must be struck and vice versa. Inasmuch as most of the letters are on the left side of the keyboard and many of them the more frequent in use, it is very probable that the right shift key is the more frequently used. However, the total number will remain the same and an equal division of the total 200, while not entirely exact, is as near as can be gotten.

V. THE CONSIDERATIONS TO BE TAKEN INTO ACCOUNT IN THE ARRANGEMENT OF AN IDEAL KEYBOARD BASED ON SCIENTIFIC PRINCIPLES, AND A SUGGESTION FOR SUCH KEYBOARD

The several considerations which should control a scientific rearrangement of the typewriter keyboard are the following:

1. The measured abilities of the eight fingers and of the right as compared with the left hand, should be taken into consideration, and loads assigned in proportion to strength.

2. The measured frequency of use of the letters of the alphabet and punctuation marks must be made the basis for calculating the loads to be assigned to the several fingers.

3. In addition to the above there are certain pedagogical considerations:

- (a) The most used letters should be assigned to the "home" or guide keys, since on a keyboard so arranged the work could be done with the fewest possible changes of position of hands. Also the frequent use of these letters will aid the pupil in the early fixing of these home-key positions.

- (b) The next most used letters should be assigned to those keys or positions which appear to be the favorable ones from the standpoint of accuracy.

- (c) Since beginners find it easier to use the first fingers than the other fingers, and since the approved method of teaching typewriting, as well as other subjects, is that of proceeding from the easy to the more difficult, it is desirable so to arrange the keyboard, by assigning several of the vowels to the first fingers, that simple practice words and sentences may be written by the beginner, even in the earliest stages of the learning process.

For purposes of the first consideration, Table XIV assembles the data from Tables X, XI and XII, i. e., the median tapping abilities of the eight fingers of high school

TABLE XIV
COMPARISON OF FINGER AND HAND ABILITIES WITH THE LOADS OF
THE FINGERS AND HANDS

	LEFT HAND				RIGHT HAND				Total
	4	3	2	1	1	2	3	4	
Mds. for H. S. Girls..	106	119	117	119	119	130	126	117	
Mds. for H. S. Boys..	127	134	145	145	156	166	164	151	
Mds. College Girls and Teachers	107	103	125	145	160	138	104	117	
Averages	113	119	129	136	145	145	131	128	1046
Multiplying these avs. by 7.56 to get ideal typewriting loads:....	855	900	975	1028	1097	1096	991	968	
The loads on the present keyboard are:....	803	658	1492	1535	1490	640	996	296	
Percentage of over- or under-load of the fingers on present typewriter keyboard:.....	-6.1	-26.9	+53.	+49.3	+35.8	-41.6	+5	-69.4	

	LEFT HAND	RIGHT HAND
Tapping ability (190,410 taps by 150 individuals)	89,593 taps	100,817 taps
	Ratio: 88.87	to 100
Present load.....	4,488 taps	3,422 taps
	Ratio: 131.25	to 100
Per cent of over- or under-load:.....	47.7	
	(over-load of left hand as compared with right.)	

girls, high school boys, and college girls and teachers, combining the three by the method of averages and showing a total of finger abilities of 1,046. Table XIV also includes the present keyboard load from Table XIII. Dividing the total keyboard load (7,910—the sum of 3,422 and 4,488 of Table XIII) by the sum of the finger abilities (1,046, Table XIV) we find that each point of finger ability must be multiplied by 7.56 so as to reapportion the whole load upon the fingers in proportion to their abilities. Comparing the ideal finger loads with the present finger loads, we find four over-loads of 49.3, 53., 35.8, and .5; also four under-loads, 5.1, 26.9, 41.6, and 69.4.

Of the 190,410 taps made in this study, 100,817 were made by the right hand, and 89,593 by the left, in equal time. Therefore the ratio of the ability of the right hand to that of the left is as 100 to 88.87, or approximately as ten is to nine. This agrees with the findings of Bryan.* The present

*BRYAN, American Journal of Psychology, 1892, V, 123-204.

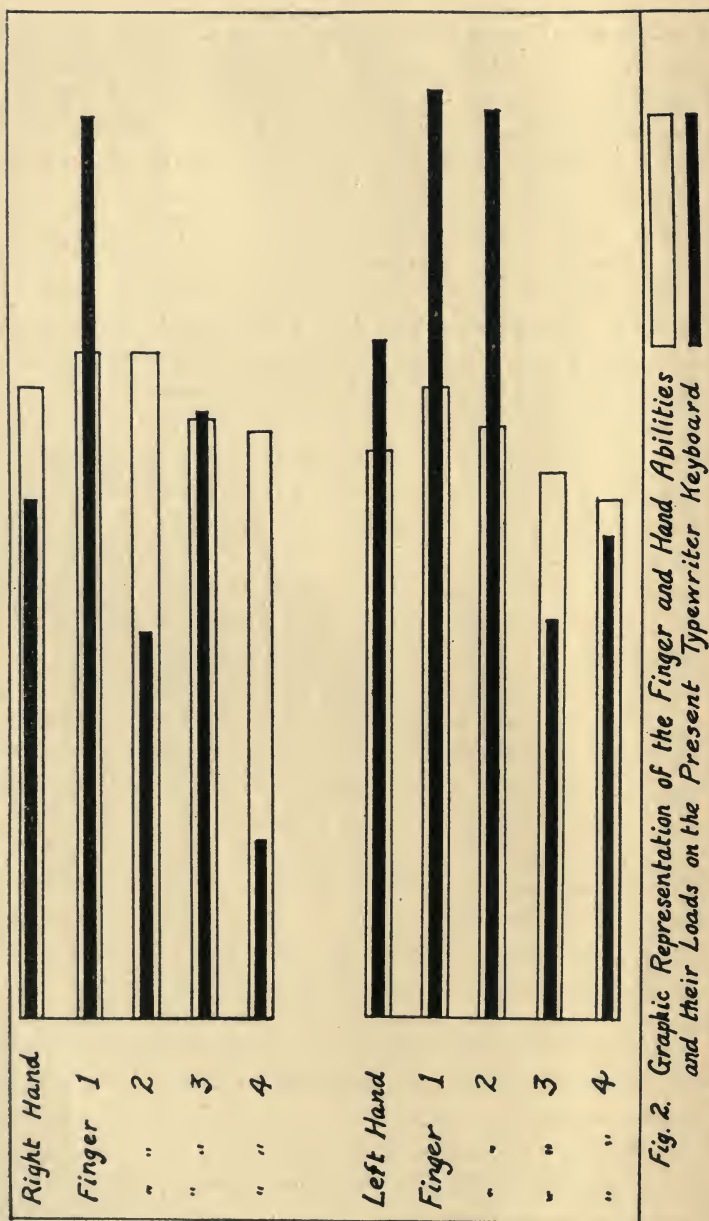
right and left hand loads in typewriting are 3,422 taps for the right to 4,488 for the left, or a ratio of 100 to 131.25. These data show an overload of the left hand of 47.7 per cent as compared with the right hand, on the present typewriter keyboard. The over-loads and under-loads discovered are more graphically shown in Figure 2.

The criticism might perhaps be advanced that in combining the measures of the tapping abilities of the several fingers as obtained on the typewriter, with those obtained in tapping on desks, two different, and for all we know, heterogeneous sets of data are being added together. In reply to this suggestion the following considerations are advanced and need to be taken into account.

First, it should be borne in mind that the same purpose was uppermost in these two sorts of experimentation, namely, the attempt to get a mathematical statement of the comparative abilities of the several fingers. The two experiments are alike in that both attempt to secure an accurate count of the number of taps each finger can make in the same period of thirty seconds, or of one minute.

Second, it is true that tapping on a desk is not, so far as we know, the same thing as tapping the keys of a typewriter in the ordinary use of that machine. But it is also true that tapping the keys of a typewriter under the controlled situation, namely, with the thumb touching the frame of the machine, beneath the space bar, may, for all we know, be no more like the process of actual typewriting than is tapping on a desk as described above. In fact, it may be that the former more nearly approximates the actual process involved in typewriting than does the latter. Both are controlled situations, with the purpose of preventing an undue influence upon the outcome as a result of leaving the arm and wrist free to do the tapping, instead of compelling the fingers to do it.

Third, of the three sets of data which are combined in Table XIV, the third (the results of tapping on desks) does not differ more from either the first (the results for high



school girls tapping on typewriters) or the second (the results for high school boys tapping on typewriters) than the first differs from the second. Therefore, an argument against including the third, because it differs from the first and second, would be just as good an argument, so far as it goes, for excluding either the first or second because it differs from the other.

Fourth, the average scores for the fingers secured by combining the three sets of data in Table XIV differ from the scores which would have been secured by combining only the two first sets of data of that table by only a little over four per cent. So far as the relative abilities of the two

TABLE XV
COMPARISON OF FINGER-LOADS OF STANDARD AND PROPOSED KEYBOARDS
WITH IDEAL LOADS

	LEFT HAND				RIGHT HAND			
	<i>Fingers</i>				<i>Fingers</i>			
	4	3	2	1	1	2	3	4
	Y	D	M	C W	Q F	V	L	P
	R	N	T	H U	S I	E	O	A
	B	P	G	J X	Z ? /	: ;
Load on above keyboard	858	888	982	1031	1098	1093	996	971
Ideal load ...	855	900	975	1028	1097	1097	991	968
Load on present keyboard	803	658	1492	1535	1490	640	996	296

hands are concerned, the three sets of data agree, all giving the ratio of approximately ten to nine. This larger result is therefore unaffected by the inclusion or exclusion of the third set of data. A study of the suggested keyboard (Table XV) will reveal the fact that it was found impossible so to assign loads as to give each finger *exactly* the proper amount of work. In the case of the third finger of the left hand the error amounts to as much as one and one-third per cent. In view of this fact the above mentioned difference of four per cent loses much of its significance.

Fifth, the fact is generally known, especially among pianists and typists, that the third finger is the least capable. This fact is not so clearly revealed in the first two sets of data of Table XIV as in the third. This may perhaps be explained by saying that the third finger, in the case of the experiment on the typewriter, being further removed from the fixed point, the thumb, than was the first or second finger, was perhaps aided somewhat in its tapping by the movement

TABLE XVI

THE ACCURACY OF HORIZONTAL LINES OF KEYS ON TYPEWRITER

Upper Line			Middle Line			Lower Line		
	Rank in use	% of errors		Rank in use	% of errors		Rank in use	% of errors
Q	25	320	A	3	87	Z	26	222
W	18	64	S	5	81	X	24	700
E	1	100	D	11	160	C	12	123
R	8	104	F	19	205	V	21	239
T	2	93	G	20	328	B	16	61
Y	15	141	H	9	56	N	7	79
U	13	100	J	23	113	M	14	162
I	6	78	K	22	234			
O	4	82	L	10	97			
P	17	46						
Averages..	10.9	112.8		13.6	151.2		17.1	226.7

COMPARISON OF THE RANK OF THE EIGHT FINGERS AND THE HANDS
IN ACCURACY AND IN LOAD IN TYPEWRITING

	Fingers	Rank in Accuracy	Rank in Load
Right hand {	1	3	6
	2	5	2
	3	2	5
	4	1	1
Left hand {	1	6	8
	2	4	7
	3	8	3
	4	7	4
Right hand	108% of errors	3422	
Left hand	192% of errors	4488	

of the wrist and arm. Should this explanation be the correct one, it would appear that the third experiment avoided this chance for error, and is to that extent a corrective. It is the opinion of the writer that the inclusion of the third set of

data in the averages gives a truer estimate of the abilities of the fingers than would be the case were these data omitted.

To return to the considerations which must be taken into account in arranging a keyboard along scientific lines, it was noted as one of the pedagogical considerations that the eight most frequently used letters should be assigned to the home keys, so far as this may be found to be possible without overloading of fingers. Also, that several of the vowels should be assigned to the first fingers, for the reason stated.

TABLE XVII
THE ACCURACY OF THE EIGHT FINGERS IN TYPEWRITING
(PERCENTAGES)

RIGHT HAND							
Fingers	1	2	3	4			
y	141	i 78	o 82	p 46			
h	56	k 234	l 97				
n	79	.	.				
u	100						
j	113						
m	162						
Averages..	108	156	89	46			
Average for the right hand: 108							

LEFT HAND							
Fingers	1	2	3	4			
r	104	e 100	w 64	q 320			
f	205	d 160	s 81	a 87			
v	239	c 123	x 700	z 222			
t	93						
g	328						
b	61						
Averages..	172	128	282	210			
Average for the left hand: 192							

From the consideration of accuracy two results might follow. It might be found that for certain vertical rows of keys, or the fingers assigned thereto, there was greater accuracy, or that for certain horizontal rows there was more accuracy than for others. These two possibilities are studied in Table XVI. In the upper half of this table accuracy is compared with frequency of use for each of the horizontal rows

of keys. In Table VIII we show that, with reference to the individual letters, accuracy and frequency of use are almost perfectly correlated. Table XVI, however, seems to show that we have the greatest accuracy in the upper horizontal line, with decreasing accuracy in the middle and especially in the lower lines, *to an extent that is not justified by use or disuse*. Since this is the case, it will be well to assign the more frequently used letters, after the home keys have been supplied, to the upper row of keys.

The second part of Table XVI, on the other hand, shows differences in accuracy of fingers, that is, of vertical rows of keys. The accuracy data are taken from Table XVII. But while the accuracy of fingers seems to differ, it appears from the table that this is due to the loads assigned to the fingers and hands, rather than to qualities of the fingers or hands themselves. For when the fingers are given their rank for accuracy and for load, we find a close correlation. The overloaded fingers tend to be inaccurate. In the case of the two hands the evidence is even more clear. The right hand with the smaller load has the better accuracy score. The average frequency of use of letters written by the left hand on the present keyboard is 291, by the right 280. So far as the law of use goes, the left hand should be four per cent more accurate than the right. Instead of this we find the right hand 84% more accurate than the left. This must be due to the over-load of the left hand.

This evidence tends to show that nearly half of the errors made by the left hand in typewriting are preventable, since they are due to the bad apportioning of the typewriting load on the present keyboard.

A further important reason why the typewriter keyboard should be scientifically rearranged is the self-evident fact that maximum speed and ease of operation can never be attained so long as some fingers are over-worked, while others do not have a chance to contribute their full share to the total result.

A rearrangement of the keyboard will, it is clear, make for improved speed and accuracy in typewriting.

The present standard arrangement of the typewriter keyboard antedates the "touch" method of operating, which has come to be the only accepted method in the teaching of typewriting. Therefore the considerations, if any, which suggested the present arrangement of the keyboard, do not apply, but new considerations must be brought to bear which take account of the fact that *all* of the fingers are to be used and should contribute their share, no more and no less.

In accordance with the above considerations we offer the preferred rearrangement of the letters and marks of the typewriter keyboard shown in Figure 3.

In addition to the improvements in the arrangement of the typewriter keyboard based on the investigations and considerations hereinbefore set forth, Figure 3 shows certain other changes from the conventional arrangement which remain to be explained. These changes are (1) the interposing between the right and left banks of keys of the shift lock, shift, and back spacer keys, and (2) the placing of the margin and tabular keys in the lower horizontal row of keys, one at either end.

In general, it may be said, first of all, that both these changes are made in an effort to make the keyboard arrangement more compact, thereby bringing all keys within reach of the fingers without unnecessary hand movements. These keys are, for the most part, usually so placed on the typewriter as to require the operator to remove the fingers from the letter keys. Furthermore, the shift key, shift lock, and back spacer are the heaviest keys on the typewriter. The back spacer operates against the tension of the machine and is probably the heaviest key of all. The shift key and shift lock usually lift either the carriage or the basket of keys. In either case, the operation of these keys requires far more force than the operation of the letter keys. It is felt, therefore, that these three keys should be placed in a central position, as in Figure 3, so that they may be operated by the

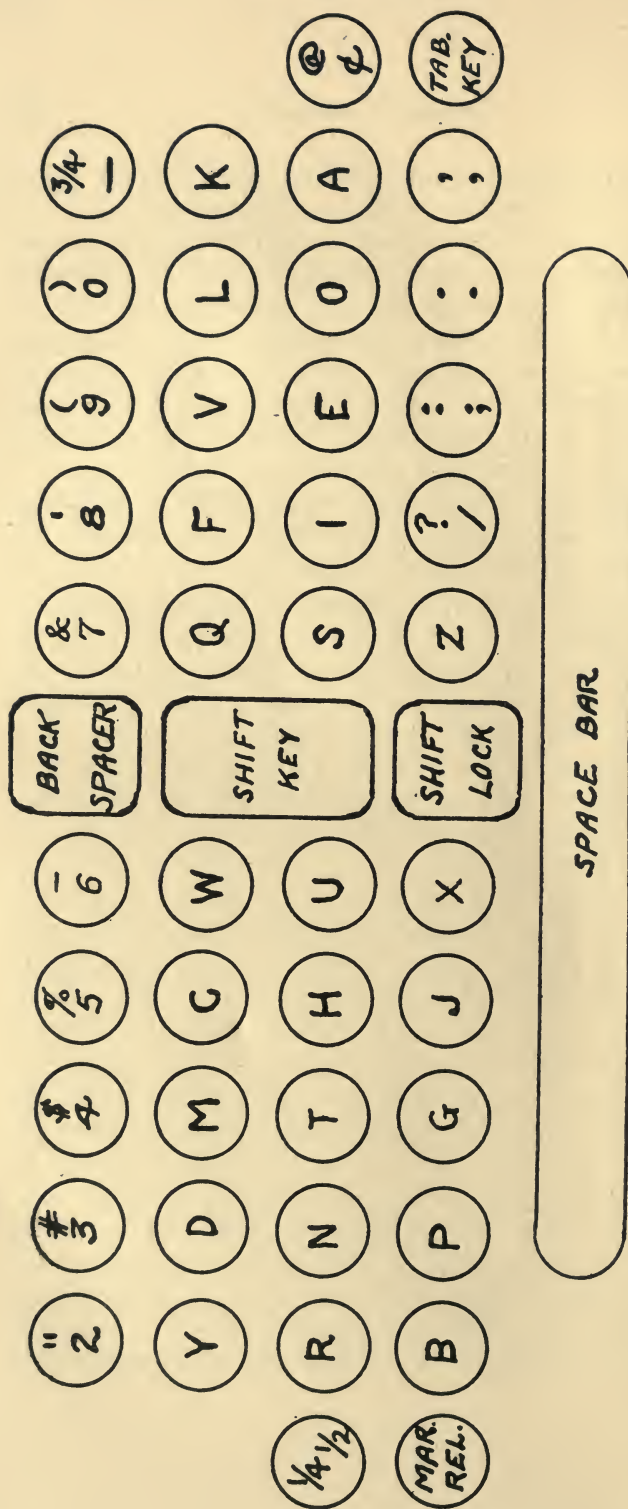


Fig. 3. Suggested Rearrangement of Typewriter Keyboard.

thumb or first finger, rather than by the fourth finger, whose strength is scarcely adequate. The margin release and tabular key are very light in touch, and not often used, so that in assigning them to the fourth fingers, as in Fig. 3, we are not unduly burdening these weak fingers.

The advantages of this arrangement are: 1. The keys in question are brought into a convenient position for operation by the thumb or first finger of either hand. 2. The entire keyboard can be operated without removing the hands from the position they take when the fingers are placed upon the "home keys," as the keys of the middle horizontal row of letters are called in touch typewriting. 3. The interposition of the shift, shift-lock and back spacer keys divides the keyboard into right and left halves, thereby tending to avoid errors and undesirable hand movement resulting from the encroachment of one hand on the territory of the other. 4. The interposed keys accentuate the importance and make necessary the confining of each hand to its appropriate bank of keys, with a minimum of movement for complete performance of the entire duty assigned it. These four advantages, together with all the other advantages claimed for the keyboard as shown in Figure 3, may be summed up, in a general way, by saying that *this keyboard is definitely planned for the most accurate and economical operation by the touch method*, the method which is now being taught in practically all schools, whereas the present conventional, so-called standard and universal keyboards have been arranged with reference to no discoverable or known criteria whatsoever.

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